# Slice Trailer Coupling System – Connection Concepts

FINAL PROJECT REPORT
by

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and

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Grant No. N00014-99-1-0818

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## ABSTRACT

This report documents a review of concepts for interconnection of a trailer and the SLICE vessel. The long-term goal is to develop a safe method of attaching a trailer to the SLICE vessel for swift and effective transport of personnel and cargo. The main objective of this particular work is to present a list of viable concepts for the SLICE/trailer connection and to identify risk mitigation measures. A summary of viable concepts found from a review of the literature is presented along with a brief discussion of the dynamics of a flexibly connected 2-Module floating system. Proper quantification of the connection's influence on the dynamic response is imperative if the SLICE/trailer system operation is to be controlled effectively.



Keywords: SLICE/trailer; Inter-modular connectors; High speed hull forms; Connection dynamics; Modal response.


### 1.0 INTRODUCTION

The Office of Naval Research (ONR) is currently involved in the development of concepts for a reconfigurable, modular, adjunct platform to a high speed hull form, incorporating SLICE technology. The adjunct platform is referred to herein as the "Trailer." Proper connection of the trailer to the SLICE vessel is a critical issue for insuring safe operation and in developing the governing dynamics for a control system. The focus of this effort is to survey potential candidate connection schemes and to assess critical issues regarding connection design. It represents a preliminary survey of concepts used in associated marine applications.

Small Waterplane Area Twin-Hull (SWATH) ships, of which the SLICE is a derivative, possess superior stability in high seas, provided that most their buoyancy is deep underwater with only narrow struts passing through the water surface. Even though this reduces their sensitivity to wave action and allows open sea operation, it also increases drag. A number of SWATH's are currently in Navy and commercial services, but are relatively slow, due to this high drag.

The SLICE ATD program has been designed to achieve both low drag and stability with high speeds. The design speed is above 30 knots. Designed towards a dual-use affordability environment, SLICE is of modular construction with a truly modular load carrying capability – either combat systems or commercial. Addition of a trailer to the SLICE will increase its load carrying ability for certain missions. One of the primary advantages of having a relatively less expensive trailer is that it can be loaded while the ship is on its way to port, thereby minimizing the time the ship must spend at port.

## 1.1 Objectives

The main objective of this report is to present a preliminary summary of viable concepts for the SLICE/Trailer connection, as a result of a literature review. Concise details of each concept are presented, along with graphical representations, where available. This work represents a first-step in the connection design process. Future objectives should include:

a) Evaluation of connector ideas and trade-off analysis.
b) Development of a list of high-level design, structural and operational requirements for the connector structural subsystem for normal, abnormal and emergency modes.
c) Development of analytical procedures for connection evaluation, once viable concepts have been selected.
d) Development of an experimental plan for connector evaluation.

# 2. Connector Concepts

This section presents a concise summary of twelve different connection concepts as a baseline for future consideration in the development of the SLICE/trailer system. These connections are labeled A through L for the purpose of this report and are summarized in Table 2.1. These are presented as an initial survey of potential ideas and as a reference point into the initial connection design spiral.

**Table 2.1 – Summary of Connection Concepts.**

| Concept | Concept Description |
|---|---|
| A | Western – Bumper and retractable latches |
| B | Plackett – Bed on the string connector |
| C | Flexor – In house connector |
| D | Flexor – Variation |
| E | Western – Hinged modules |
| F | Flexor – Pontoon and pipe connection |
| G | NFESC – Rigid connector |
| H | ARC – Keel connector |
| I | McDermott – Compression only nonlinear compliant connector |
| J | Simple hinge connector concept |
| K | Stroking center connector |
| L | Roller connector |

## 2.1 – Concept A, Western – bumper and retractable latches

A connector with a bumper and retractable latches was developed by Western Instrument Corporation [Plackett, 1993]. A general layout of this concept is shown in Figure 2.1. The connection consists of rectangular modules with the following hardware: (a) an elastomer corner bumpering system that provides collision protection to the modules, (b) portable hydraulic deck winches that pull the modules together through hawsepipes located just below the centerline of each module, and (c) a retractable latching system that utilizes a worm gear linear actuator as the mechanical drive (see Figure 2.2).

The connection follows bumpering, pull-in and latching steps. The latches are made retractable for stowage during transit and to prevent damage before the modules are aligned for connection. The movement and locking of the latches can be actuated manually or with hydraulic cylinders. The pull-in method consists of two warping lines, rigged between modules below this centerline, to pull the modules together. Two pulling devices, such as winches, are required per "pull-in" operation. The lines used to pull the modules together will increasingly restrict the relative motion between modules. Once pulled tight together, they will be roughly aligned for final latching. The pull-in lines are terminated at a compliant deadman fitting. Possible concepts for the compliant deadman are shown in Figure 2.3. The final connection is accomplished by the use of a simple retractable latch system. The latch pins are driven into the adjacent receptacles with a power unit. Locking keys are then driven into the pins to lock the modules together.

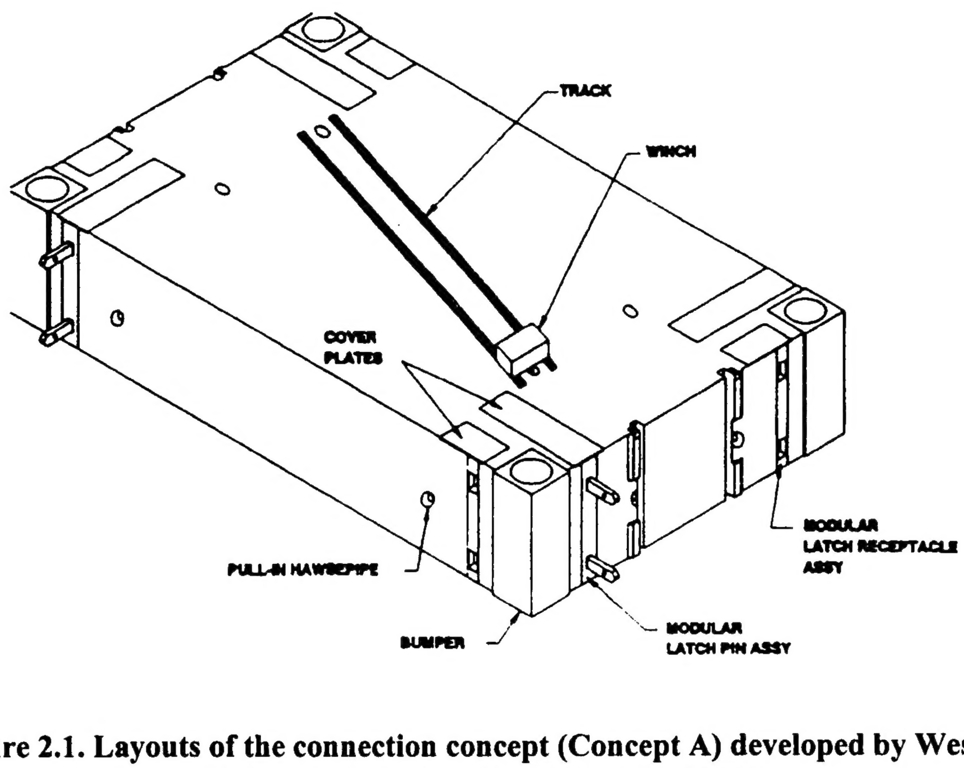



**Figure 2.1. Layouts of the connection concept (Concept A) developed by Western Instrument Corporation, [Plackett, 1993].**

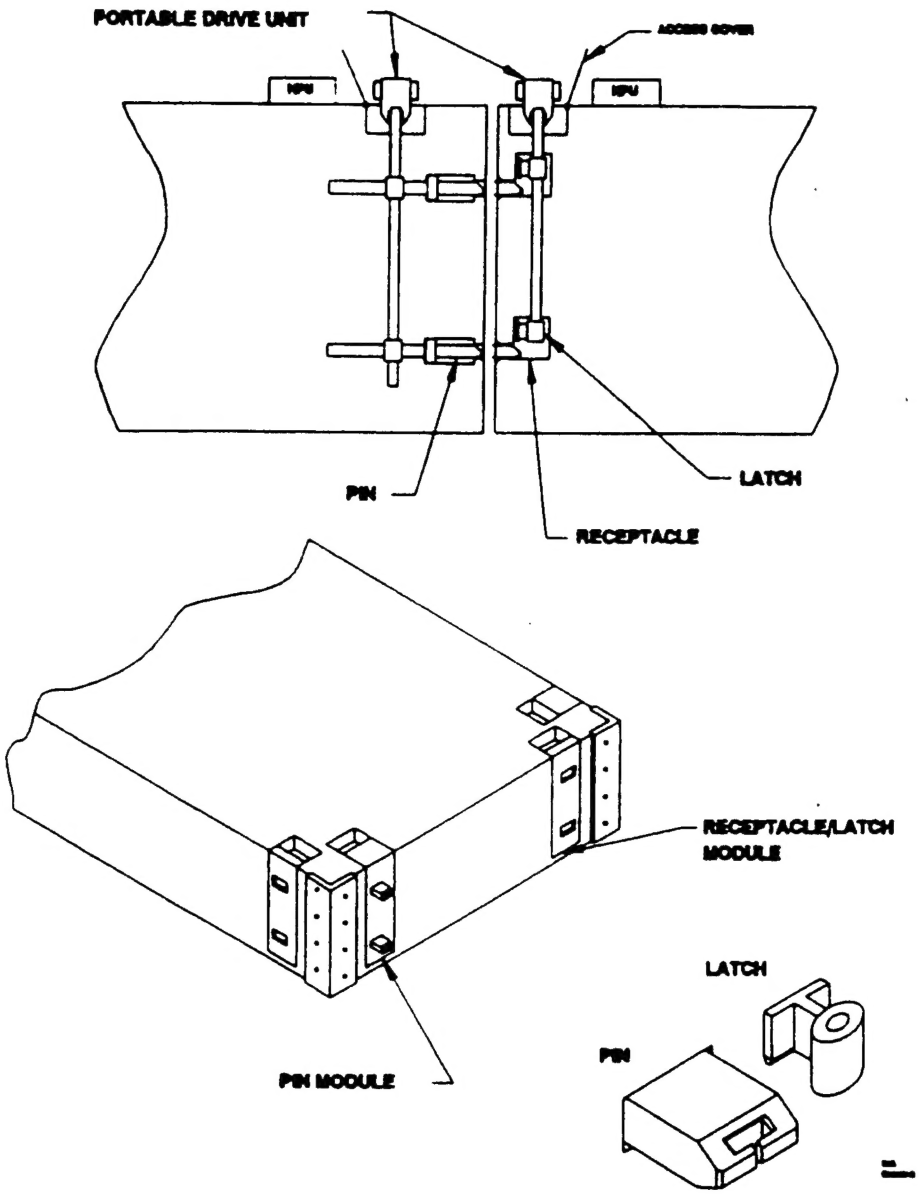



**Figure 2.2. Retractable latches (Concept A), [Plackett, 1993].**

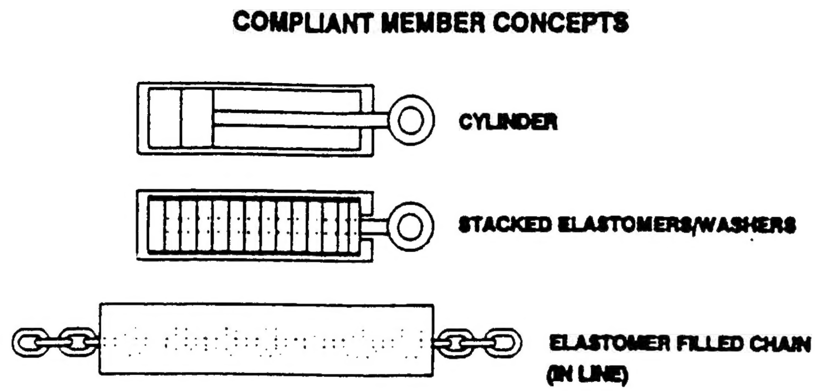



**Figure 2.3.** Possible concepts for the compliant deadman, [Plackett, 1993].

### 2.2 – Concept B, Bed on the string connector

Developed by Western Instrument Corporation, the bed on the string concept is composed of a system of internal pipes with cables prepositioned inside, an inflatable fender system, a sphere alignment unit and retractable pin connectors, [Plackett, 1993]. Structural layouts of this concept are shown in Figure 2.4.

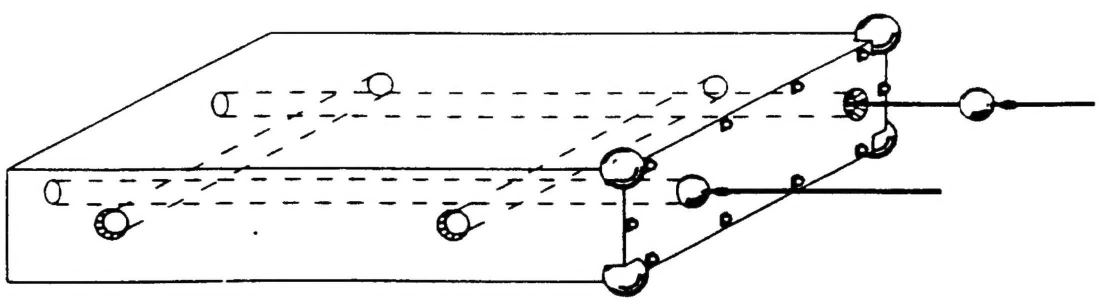


**Figure 2.4. Layouts of the bed-on-the-string connector, [Plackett, 1993]**

The modules are brought into contact in a unique "beads-on-the-string" (Figure 2.4) procedure, while taking the string of modules underway. The towing lines will guide the sphere alignment assembly into a funnel-shaped trap at the end of the pipe. The combination will maintain the modules in alignment for the final installation of the connector pins. Fenders are placed at the four corners of the adjoining faces to protect

the modules from collision impacts (keep modules apart.) The fenders have to be inflated for deployment. See Figure 2.5 for possible fender arrangement.

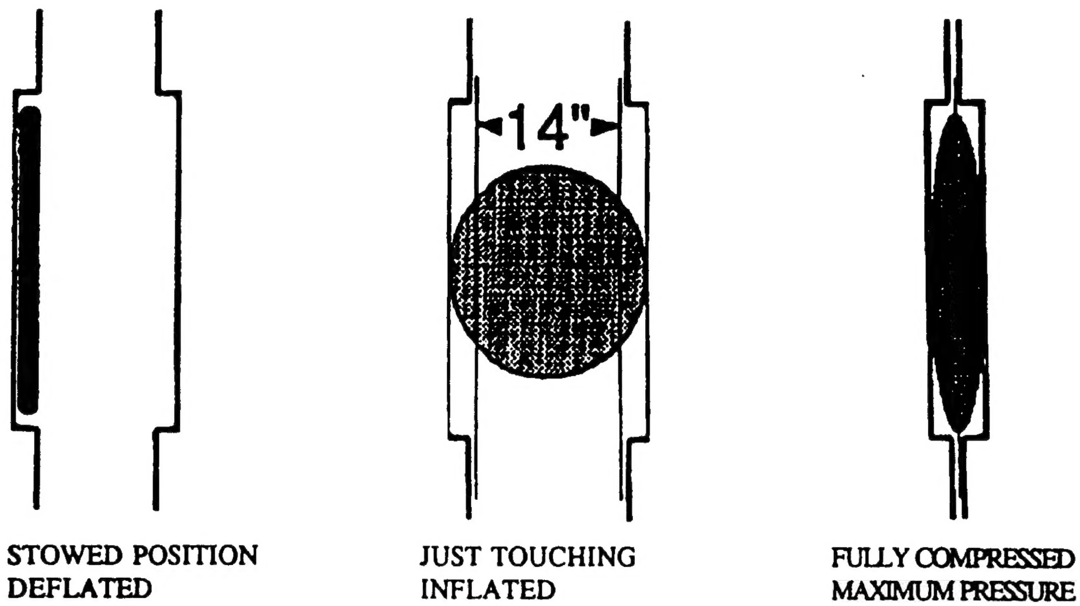



**Figure 2.5. Possible arrangement of inflatable fenders, [Plackett, 1993]**

As the modules are brought into contact, the fenders flatten and provide progressively increasing contact area. Simple relief valves prevent overinflation. Once the pin connectors have been inserted to resist the wave-induced loads, these fenders can be completely deflated and retracted into their recesses, in order to eliminate further wear.

The sphere assembly actuates the initial alignment between modules and resists the shear forces temporarily to allow further connection actions. The sphere is fitted with two short stems on opposite sides, which are further attached to the end of cables contained in tubes, as shown in Figure 2.6.

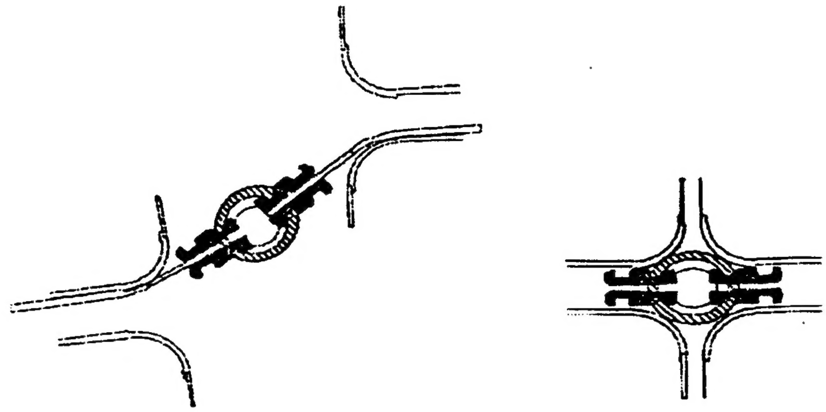


**Figure 2.6. Sphere connectors aligned with receptacles, [Plackett, 1993].**

The cables are tensioned by winches to bring the modules together and guide the sphere into the corresponding trap when the gap is closed up. Once the pin connectors are in place, the sphere assembly may be locked with guillotines at the inboard ends of the stems to form a redundant rigid connection system. A pictorial representation of the connector pins and operating components are shown in Figure 2.7.

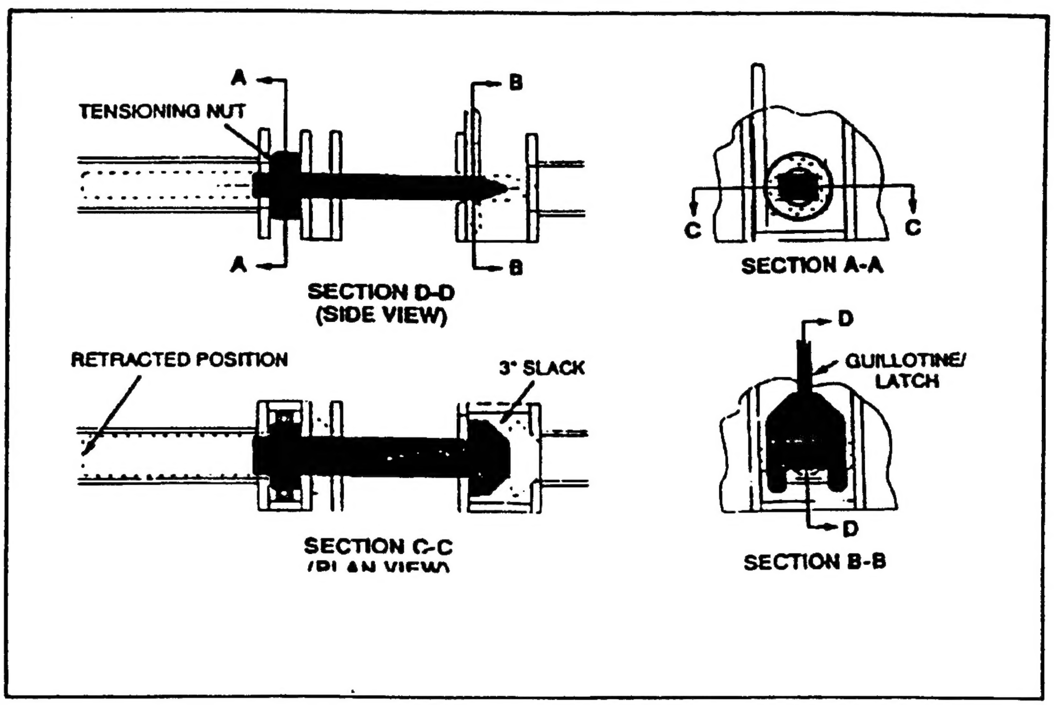



**Figure 2.7. Details of connector pins and components, [Plackett, 1993].**

## 2.3 – Concept C, Flexor – in house connector

For the Flexor in-house connector concept [Hatch, 1985], shown in Figure 2.8, the installation procedures for rigid and flexible connections are nearly identical. Major components include corner fender, compliant alignment assembly, and spring-loaded large stab pins. The corner fenders are solid elastomer cylinders along the entire vertical edges of the adjoining faces. These fenders provide general protection to the modules from collisions at a sharp angle.

The compliant alignment assembly is a low cost imitation of the NL flexor. It consists of a short chain section partially molded with elastomers. The assembly is held at the inboard end and stored in the stowage housing for transport. In operation, the outboard ends of the alignment assembly will be connected to the warping lines and thereby pulled into the corresponding receptacle on the other module. At a short distance, the alignment assembly could very well reduce the relative motion between modules. The stab pins are also retracted and stored within the module and can be extended shortly before connection begins. A fully extended pin will rest on a spring support to form a resilient member.

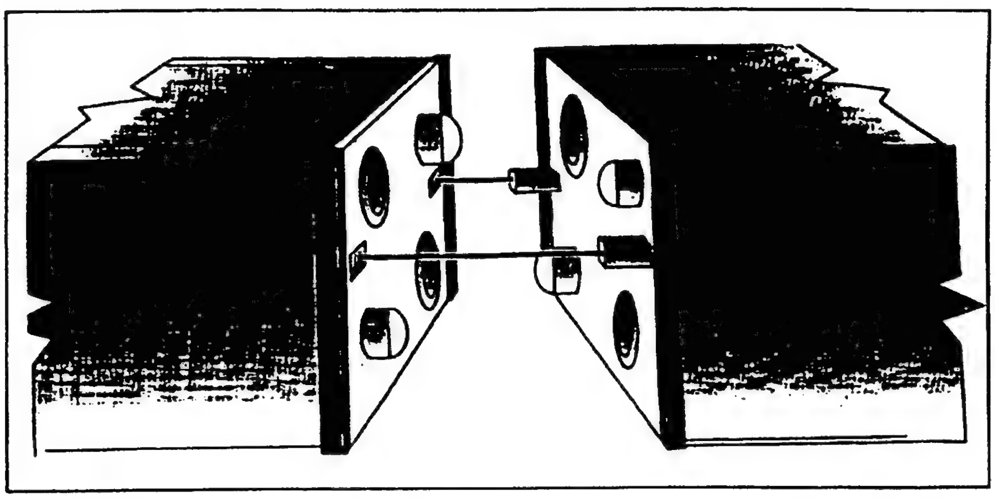


**Figure 2.8. Structural layouts of the in-house connection, [Hatch, 1985].**

The pins are the permanent load-carrying members of the connection system. The spring-loaded pins will retract to absorb the impact energy as a fender system before they are properly located in the receptacles. This connection system does not require simultaneous alignment of all connector members at once. Shallow funnels are equipped around the receptacles for the stab pins to assist in the location of the pins. No power unit is required on the adjoining modules.

In operation, this concept uses a bridle marriage system that attaches to the ends of the compliant causeways to bring together the adjoining modules. Modules will be attached to a tender boat as soon as they are launched from the delivery ship. The adjoining modules will be brought approximately in line with each other at a safe separation to avoid collision due to wave-induced motion. The modules will be gradually pulled in with marriage bridles. The marriage bridle is deployed on the module without Flexor assembly. The marriage bridle is connected to a winch wire, which is fairled to the center of one end of the adjacent causeway, outhauled down the length of the center string, and attached to a pair of 1-inch wire bridle legs. Stab pins are extended at this stage. The legs fork to opposite sides of the section through cleats and pass to the end of the trailing section. At a separation of 30 to 35 feet, the wire bridle allows each section to heave, pitch, sway and yaw without too much resistance. The motion of one causeway is increasingly transferred to the other as the bridle is hauled in and the wires become shorter. Meanwhile, two messenger lines, which are connected to the ends of the bridle legs, are passed to the other modules to transfer the bridle legs for connection with the Flexor assembly. As the separation decreases, the load on the bridle wire increases as the sections try to move in response to the waves.

### 2.4 – Concept D, Flexor – variation

Concept D is a variation of the Flexor connector, which has been proposed to eliminate the pipe connectors, so that the barges can be designed with flush ends. The new connector concept uses a flexural member and two short rigid members connected with ball joints. The new flexible connector is shown in Figure 2.9.

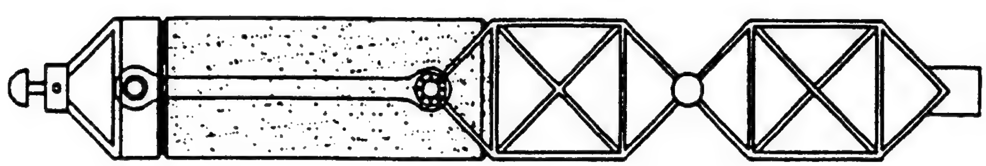


**Figure 2.9. Variation of the Flexor connector, [Huang, 1996].**

The joint between two rigid members allows large rotations, while the other joint is partially supported and allows only limited rotations. The entire link can be retracted and stored in a housing similar to the Flexor connector. The flexural member serves as an

alignment tool and the two rigid members combine to replace the pipe connectors and resist shear forces.

The inboard end of the flexural member is equipped with a railroad coupler that locks to the end of the receiver. The other end of the link can be locked with a guillotine. For the purpose of transmitting compression force, a guillotine-type stopper can be provided at the inboard end of the middle rigid component. The stopper constrains inbound movement of the middle rigid component but not the outbound movement so as to complete the function of transmitting the axial forces.

Designs of the component members can be of various forms. Connection is made in similar manner to the NL Universal End Connector Assembly. The connector is held by a chain or wire at the inboard end and attached to the bridle leg at the outboard end. The bridle pulls it out. Before the middle rigid member is completely pulled out of the housing, the flexural member acts like a Flexor by gradually constraining the relative movement between modules. The middle member is then pulled into position in the receiver. At this moment, the guillotines are locked in place to hold the connector link

## 2.5 – Concept E, Western – Hinged modules

Proposed by Western Instrument Corporation, the purpose of this concept was to limit the connection bending capacity requirement. The hinged modules can be the same size and installed with the same equipment as the regular modules, as shown in Figure 2.10. With hinged modules, on-site barge construction is reduced to rigid connection only. However, the hinged modules connected with simple pin joints are not suitable for lifting by a standard ISO strongback, given that the module will tend to buckle under its own weight at the hinge joints.

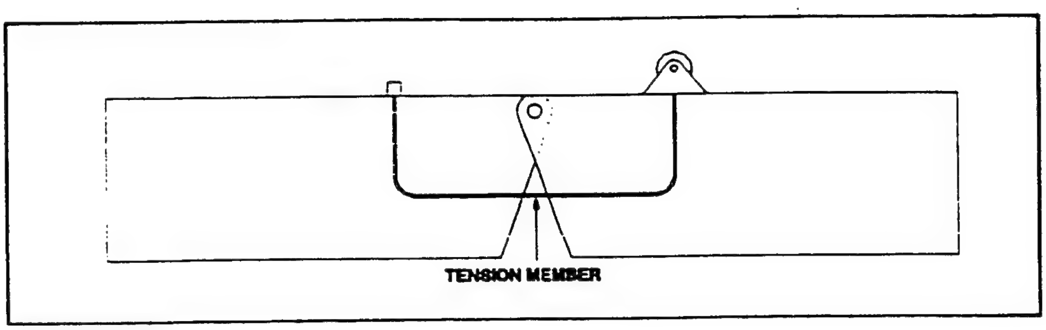



**Figure 2.10. Hinged modules, [Plackett, 1993].**

A tension member is added to restrict the ability of the module center to fall. This is shown as a wire rope through the pull-in hawsepipes. Once the module is set in the water and the strongback removed, a quick release can be actuated to free the module hinge.

The disadvantage to this concept is that the wire rope only works in tension and may be subject to snaploading until the quick release is actuated.

**2.6 – Concept F, Flexor – Pontoon and pipe connection**

The P-8 Pontoon Flexor and Pipe Connector [Hatch, 1985], as shown in Figure 2.11, is the only existing flexible connection system that has shown at least some open sea capability. This concept represents the status of the open sea connection technology and will serve as the baseline for the assessment of new technologies.

The standard Navy pontoon connector consists of male and female pipe couplings that absorb shear and compression forces, and a universal flexor to handle loads. The P-8 Pontoon assemblies house the Flexors. The P-8's are outfitted with pipe/socket shear connectors that absorb lateral and vertical shear loads, as well as compressive loads. The P-8 Pontoon assemblies consist of P-8 left and right pontoon with Flexor receivers.

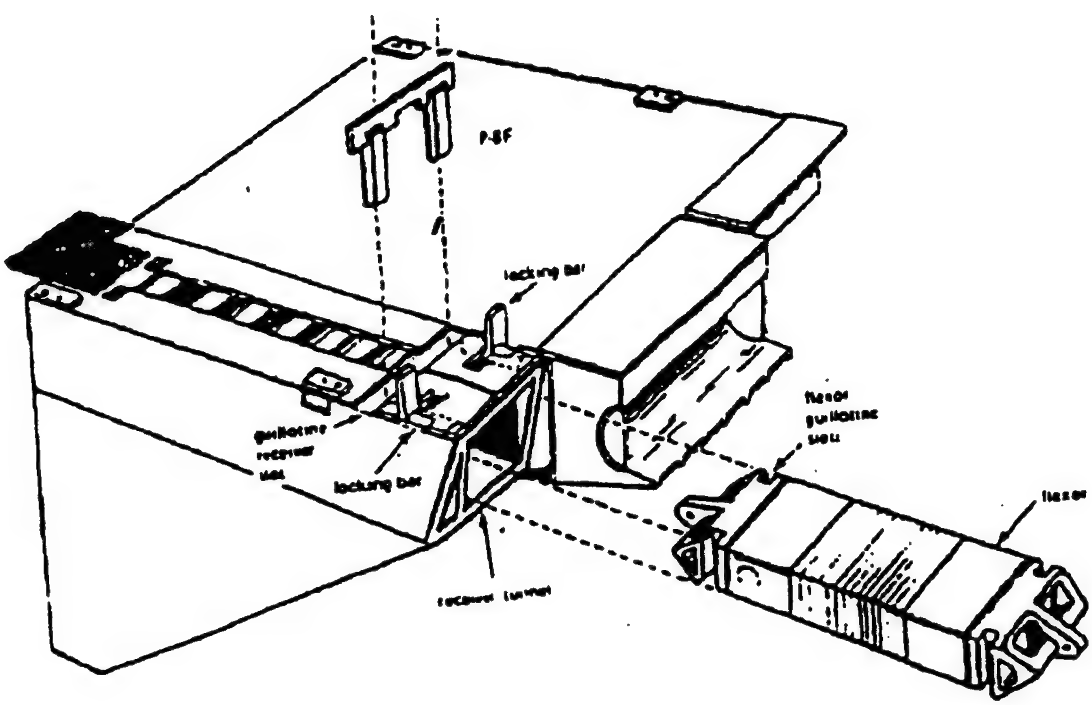



**Figure 2.11. P-8 Pontoon Flexor and Pipe Connector, [Hatch, 1985].**

The P-8 left pontoon is fitted with a female shear connector. The right and left modules are separated by a center pontoon that is fitted with a male and a female shear connector, but no Flexor. The Flexors receivers are reinforced box structures that utilize a removable guillotine to lock one end of a Flexor in position. The housings are used as structural terminations for the operational Flexors, as well as protective enclosures for Flexors during transport. The nominal dimensions of the Flexor connector are shown in Figure 2.12.

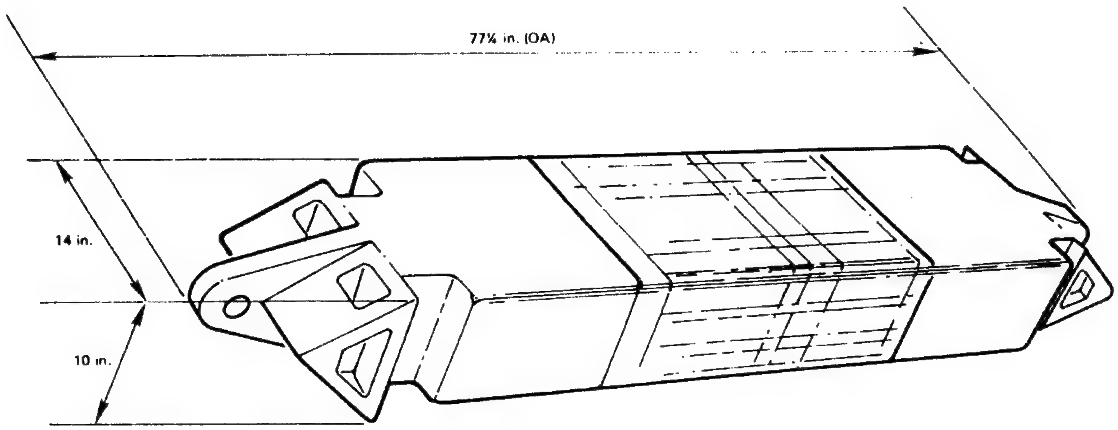
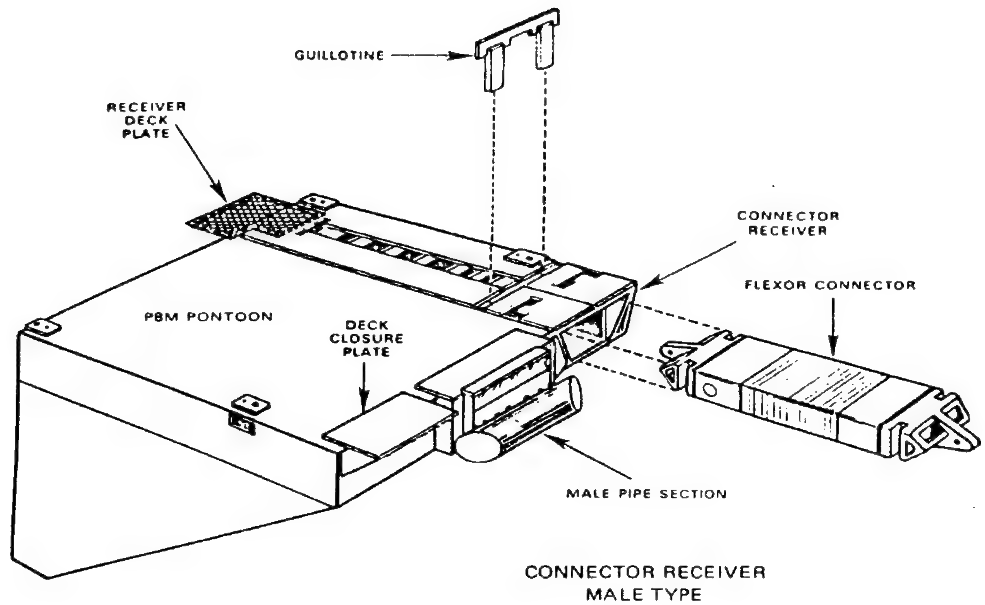



**Figure 2.12. Nominal dimensions of the Flexor connector, [Hatch, 1985].**

The guillotines are one-piece U-shaped plates of high strength steel that are dropped through an opening in the deck of the receiver when the matching slots in the Flexor are aligned. Once the guillotine is fully seated in the slot, two locking bars are moved into position to assure that the guillotine remains in place. The deck of the Flexor is partially covered with a hinged grating that can be swung open for access to the inboard end of a Flexor that is stowed within the receiver. The components of the P-8 male and P-8 Female Pontoons are shown in Figure 2.13. In Figure 2.14, a cutaway shows the interior Flexor components.



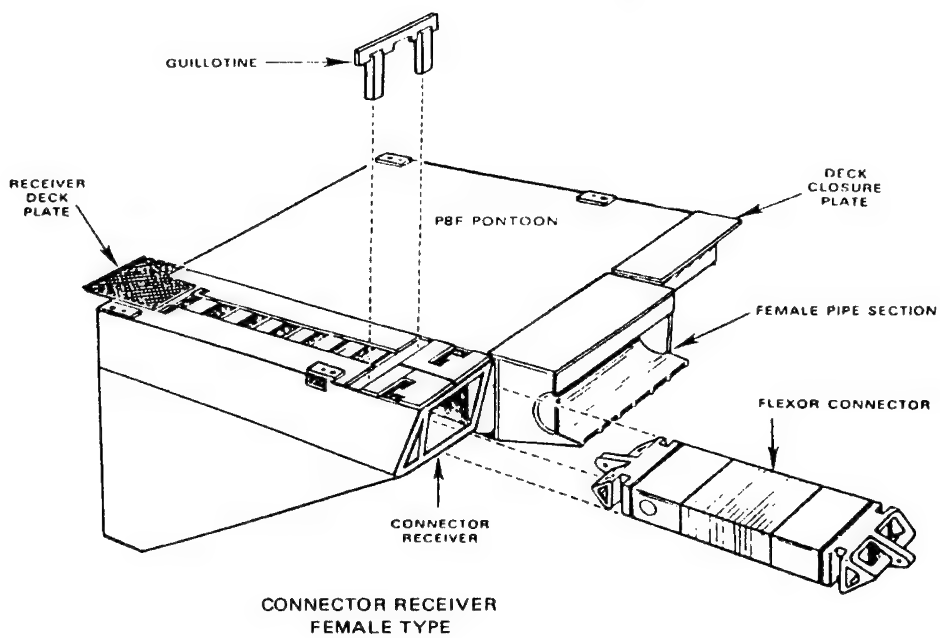




**Figure 2.13. Components of the P-8 Male and P-8 Female Pontoons, [Hatch, 1985]**

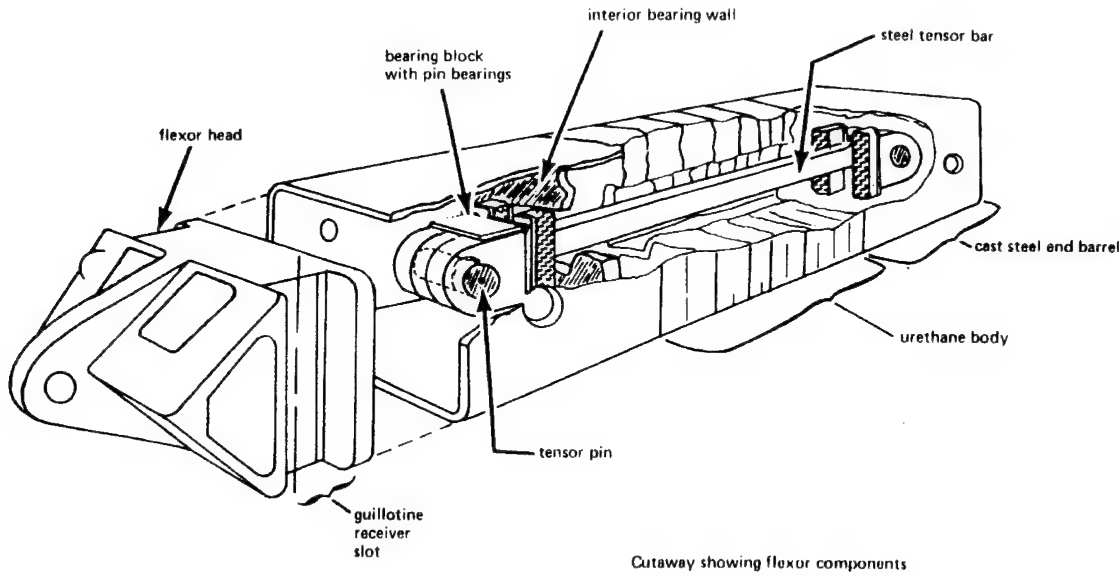



**Figure 2.14. Cutaway showing interior Flexor components, [Hatch, 1985]**

## 2.7 – Concept G, NFESC – rigid connector

Developed by the Naval Facilities Engineering Service Center [Huang, 1985], this conceptual rigid connection consists of a rigging system that gradually draws the pontoons together under pretension and near the end leads a pair of compliant alignment pins into mating receptacles.

The overall arrangement of components in the connecting system is displayed in Figure 2.15. The system is modular in construction, so that all components, except the intermediate-connecting alignment pins, are housed within the universal, removable structural frame.

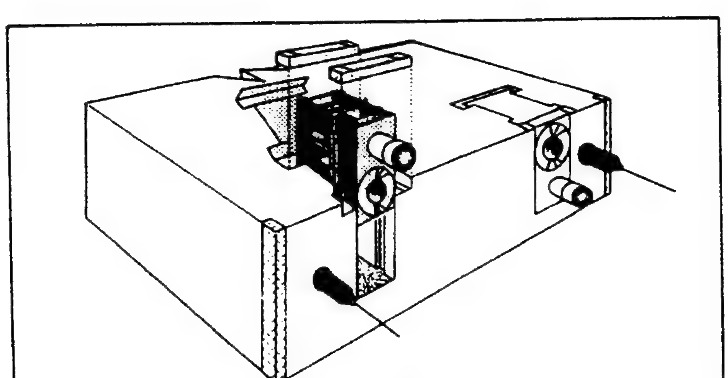


**Figure 2.15. General layout of the rigid connection system, [Huang, 1985].**

The alignment pins are stowed in cylindrical housings attached to the pontoon at mid-height, just outboard of the rigid connector modules. An elastomer corner fender is installed at each vertical edge of the pontoon. A detailed structural layout of the rigid connector assembly is illustrated in Figure 2.16.

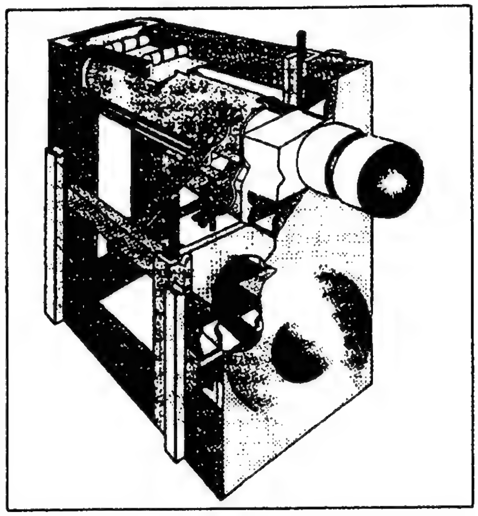


**Figure 2.16. Detailed structural layout of the rigid connector, [Huang, 1985].**

This connection system does not require simultaneous alignment of all connector members. It works gradually and takes advantage of random wave-induced motion to find the receptacle by means of hit-or-miss action. The pins, when locked to the receptacles, carry the tensile loads induced by weights and motions. The connector frames, on the other hand, carry the compressive loads.

The alignment pins provide the transition between free-floating individual pontoons and hinged couple, as mating takes place. Alignment pins are stowed in a housing fixed to the pontoon structure itself, outboard of the connector modules. The alignment pin concept is shown in Figure 2.17.

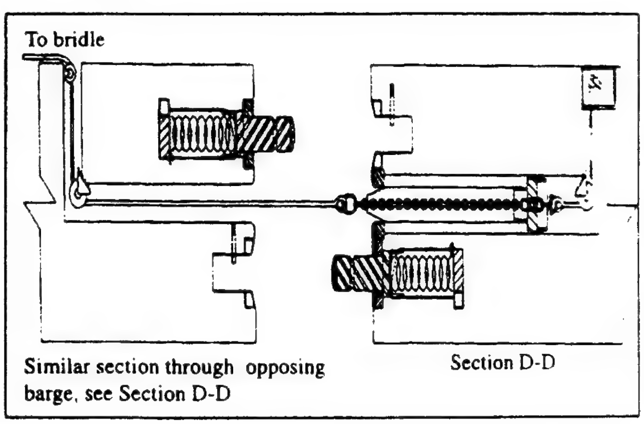



**Figure 2.17. Alignment pin concept, [Huang, 1985].**

## 2.8 – Concept H, ARC – Keel connector

Developed by the Atlantic Research Corporation [Derstine, 1999], the keel connector was designed based on the general arrangement of the MOB modules with two separate pontoons. Thus, "point" connectors were selected for the configuration of the lower connectors. NASA's six-degree of freedom joint seemed to provide the desired compliant properties for these connectors.

With compliance in all six degrees of freedom, it will allow the global behavior of the joint to be governed by the characteristics of the upper connection. By including the capability for varying the compliance in the lower connection, it will act to further resist the motions of the upper connections, while allowing greater compliance during engagement and sea states greater than 6.

The general arrangement for the 6 DOF keel connector is shown in Figure 2.18. Indicated in the figure are the parameters that can be varied. The connector consists of an array of tubes on each of its four sides. The tube spacing between both rows and columns is constant throughout the connector (d). The number of rows and columns (row, column) is also held constant on each side, as well as the tube diameter (dia), thickness (t) and length (L).

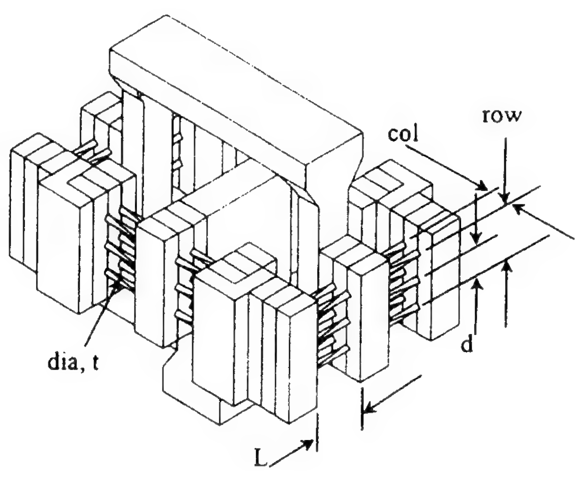



**Figure 2.18. Keel connector concept, [Derstine, 1999].**

## 2.9 – Concept I, McDermott – compression only nonlinear compliant connector

Developed by J. Ray McDermott Engineering [Mills and Chen, 1999], this connector consists of conventional cell-type marine fenders that buckle at a low load. The schematics of this concept are shown in Figure 2.19. As the load increases beyond the buckling load of the small marine fenders and the deflection provided by buckling is used up, the higher load is carried through a steel cylinder to the larger concentric rubber

cones, which have a higher buckling load capacity and a larger allowable deflection. The larger rubber device is designed to absorb some of the energy associated with the wave-induced random motions. Also, it provides sufficient restoring moment under any unbalanced mean yaw moment.

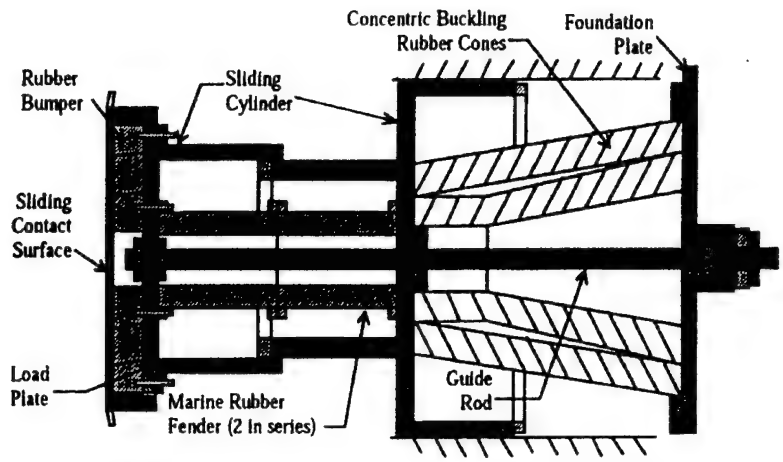



**Figure 2.19. Schematics of the compression-only non-linear compliant connector, [Mills, 1999].**

One advantage of this design is that it greatly simplifies the connection operation. Only one connection is required at the centerline joint. Because of the expected low wave loads associated with sea state 5, for which the connection is designed, the hydraulic system of the retractable part can be designed to a small load associated with the weight of the moving part and the buckling load of the small fenders. Once the locking pins are engaged, the hydraulic system will be shielded from any load increase in higher sea states.

## 2.10 – Concept J, Simple hinge connector concept

For the docking probe concept [Haney, 1999], shown in Figure 2.20, the docking probe engages the docking slot first and controls the relative transverse position of the two semi's (semisubmersible vessels) accurately enough that the toggle noses enter the toggle nose receivers without interference. The toggle noses are forced into the toggle nose receivers by the thrusters of the semi's. A toggle nose houses two opposed transverse pins that are driven by a toggle (see Figure 2.21).

The toggles drive the 45-degree tapered ends of the transverse pins into complementary sockets on the toggle nose receivers, in order to make the connection between the semi's. To disconnect, both toggles are driven simultaneously back across center by the hydraulic

rams. Simultaneous action must be assured by the logic of the hydraulic control circuit. Once the toggles are past center, the connectors have no load carrying capacity. Thus, the toggles act as triggers to release the load in the connectors safely and without damage.

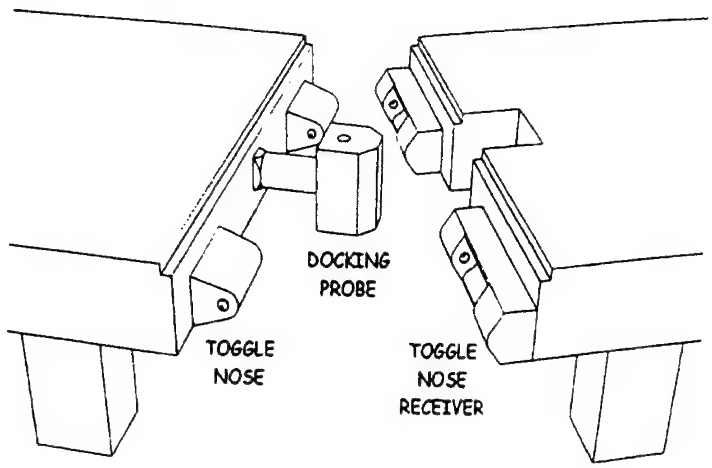



**Figure 2.20. Simple hinge connector concept, [Haney, 1999].**

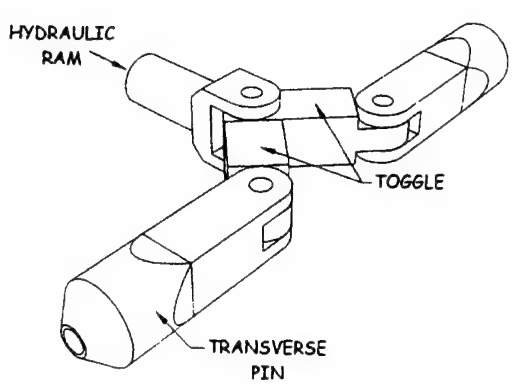



**Figure 2.21. Pin and toggle assembly, [Haney, 1999].**

## 2.11 – Concept K, Stroking center connector

The stroking center connector [Haney, 1999], shown in Figure 2.22, was developed to eliminate longitudinal impact of the central ball joint during docking, given that it can stroke longitudinally. The roll shaft is coupled to another shaft, which projects through a number of devices. The shaft is connected to the jack array via the load cap. The damper is connected to the inboard end of the semi. At its other end, it is connected to a bulkhead inside the shaft.

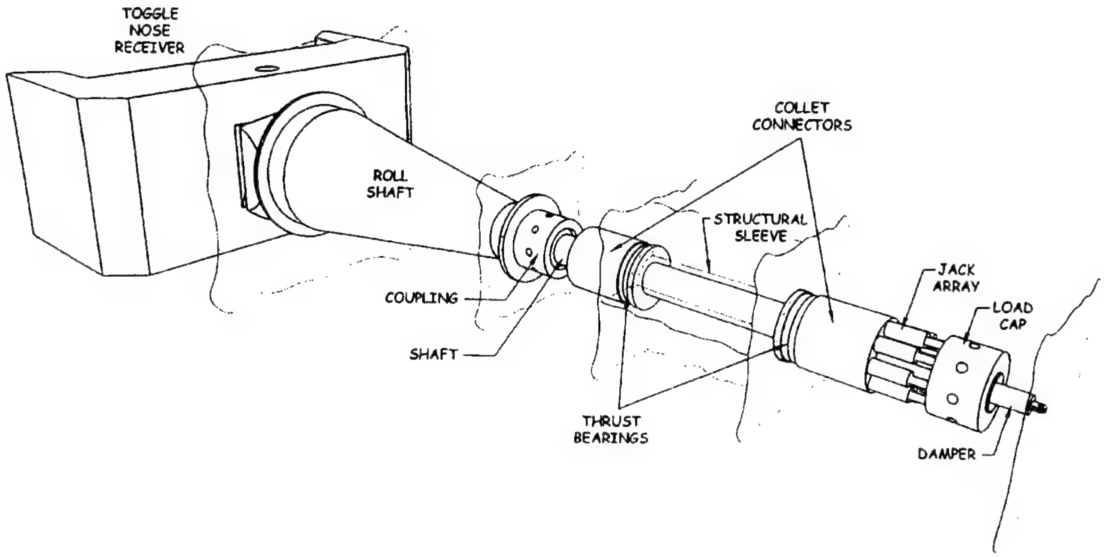



**Figure 2.22. Stroking center connector, [Haney, 1999].**

The jacks are made to act as springs, by placing compressed nitrogen over the hydraulic fluid. Once the connection is made the collet connectors grip the shaft and deliver the axial load in the shaft, through the thrust bearings, into the structural sleeve, which is built into the semi.

## 2.12 – Concept L, Roller connector

The roller connector [Haney, 1999] is shown in Figure 2.23. For this concept, the compliant elements are the large, rubber, buckling cones, which can utilize collinear damping devices. The cones back up a longitudinally sliding box structure, which supports a roller. The roller consists on six large steel wheels, mounted on two collinear axials. The roller bears against a vertical-bearing surface, mounted on the opposite semi.

The roller connector offers advantages, such as: the tensioner can be eliminated; the wheel and axial bearings can be sealed and lubricated; the whole process is simpler and less susceptible to damage.

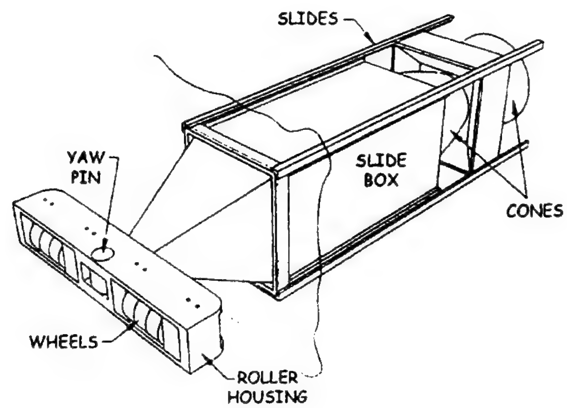



**Figure 2.23. Roller connector, [Haney, 1999].**

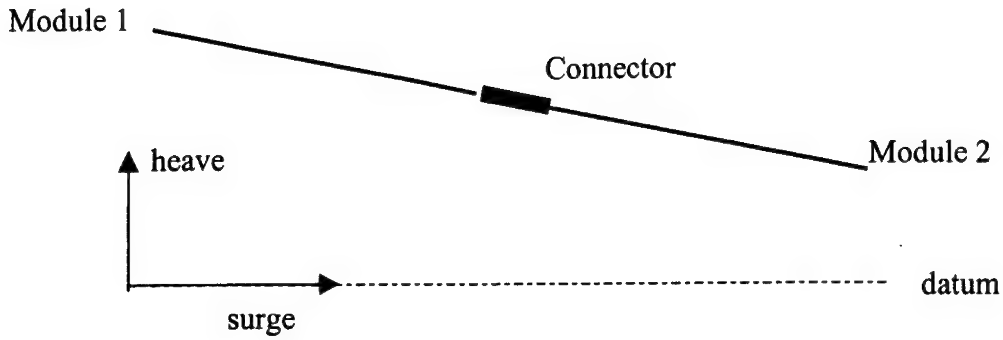
## 3. INFLUENCE OF THE CONNECTIONS ON THE DYNAMICS OF A 2-MODULE SYSTEM

Intermodular connection response will have a pronounced impact on the dynamics of a multiply connected floating system. The global response and dynamic characteristics will be highly influenced by the connection rigidity. In addition there will be a hydrodynamic interaction between the modules, which can be rather significant. A very rigid interface between the SLICE and trailer will cause the system to act as a single unit. In all likelihood it will not be feasible to employ a relatively rigid connection between the SLICE and the trailer. Therefore, the connection will be partially restraining and changing its rigidity will cause changes to the natural frequencies and modes of the system.

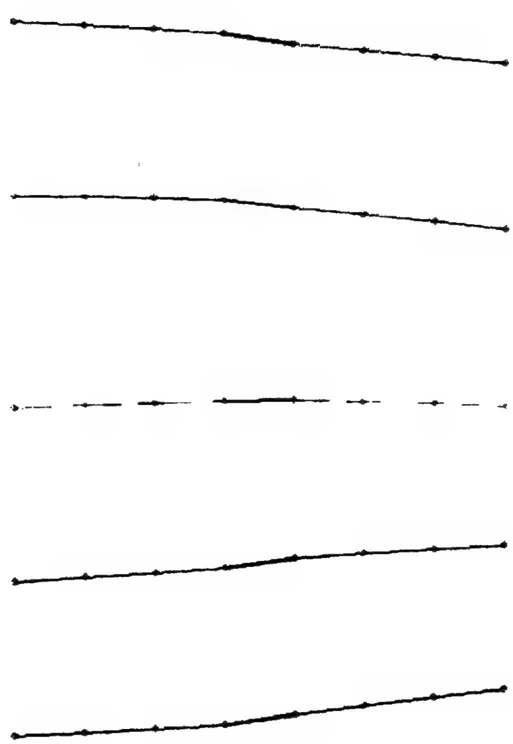
Studies of the 2-module Mobile Offshore Base (MOB) testing program can be used as a baseline for understanding the various modes of dynamic response [Venkataraman, 2001] of a flexibly connected system. The actual dynamic characteristics of the SLICE/trailer will depend upon the specific dynamic characteristics of the SLICE, the trailer and the connection between them. In the two module MOB several of the "classic" modes observed in ships were seen in the MOB studies. Combined heave and pitch response where the connector response is, for practical purposes, in line with the 2 modules was observed as portrayed in Figure 3.1. In this case the relative pitch angle of Module 1 and Module 2 is the same and in phase. Forces induced in the connector will be minor in this mode.

A mode was also observed where the entire system was in combined heave, pitch and sway where the pitch and sway of the two modules was out of phase. This mode is demonstrated in Figure 3.2. The vertical direction response is apparently the first flexural response of the system, which is highly dependent on connector stiffness. From observation of the mode shape derived from actual tank test data it is observed that the individual modules behave primarily in a rigid fashion with nearly all of the flexing occurring through the connector. A mixed mode as such has the potential of imparting large connector forces as the modules move relative to each other. This response must be considered in control system design.

As another example, a similar condition exists in roll response. For the 2-module system a mode was observed where the entire system rolls in phase about the longitudinal axis. A mode also exists where the modules behave with roll angles out of phase causing potentially high force levels at the connectors as shown in Figure 3.3. This can be thought of as torsion of the entire system. This mode was observed during head seas due to inherent asymmetries in the physical system. The response in this mode will be strengthened in quartering seas.



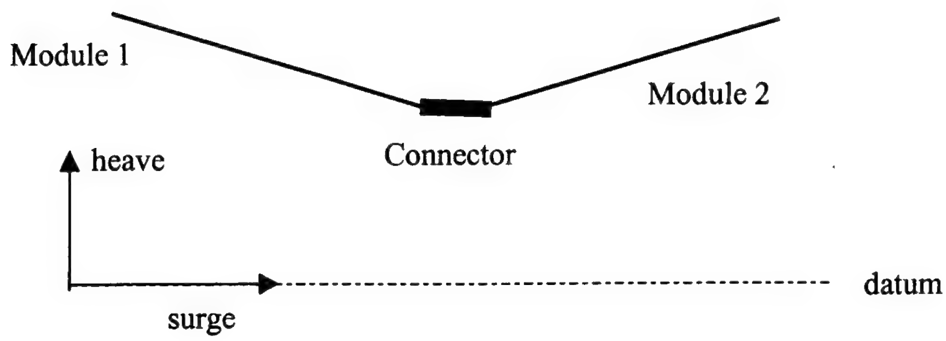

a) idealized



Side View

b) Response of 2 module MOB at 0.507 Hz subjected to OCHI head seas.

**Figure 3.1. Combined heave and pitch of a 2-module system.**

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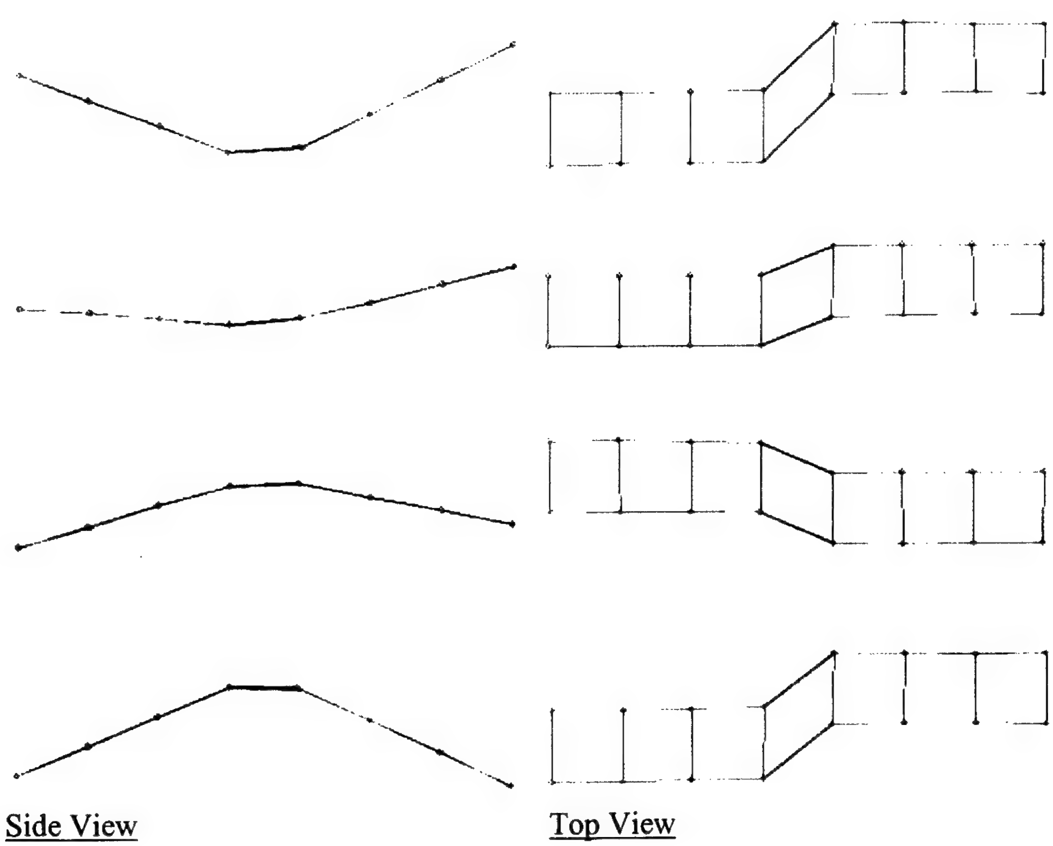
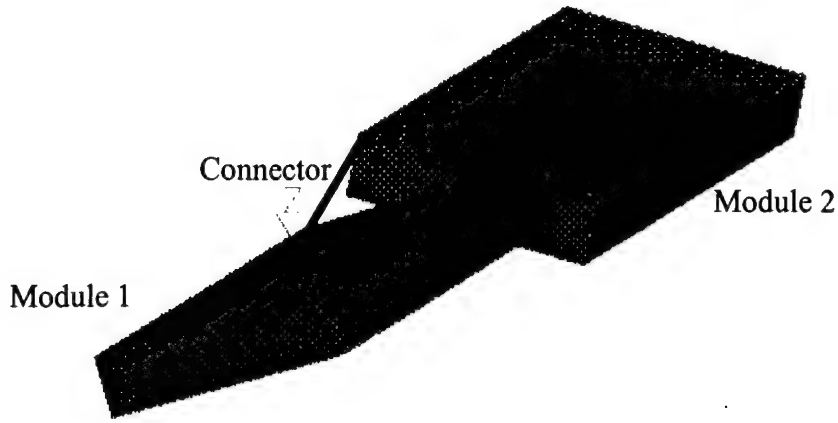



b) Response of 2 module MOB at 0.429 Hz subjected to OCHI head seas.

**Figure 3.2. Combined heave and out of phase pitch and sway of a 2-module system.**

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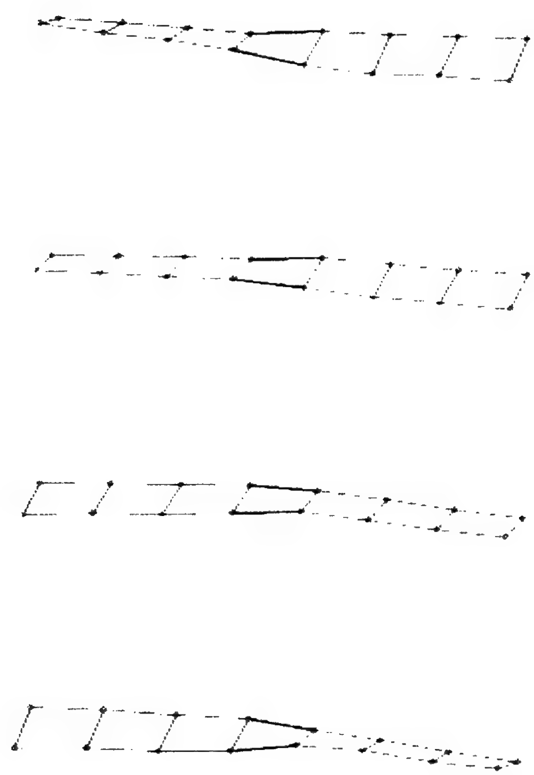

Isometric View

b) Response of 2 module MOB at 0.429 Hz subjected to OCHI head seas.

**Figure 3.3. - Out of phase roll response (1st Torsional Mode) for a two-module system.**

## 4. Summary and Conclusions

The SLICE/trailer system can be used as a rapid deployment platform for military operations. This can result in a high degree of mobility and a rapid response time for at sea operations. A significant challenge in implementation of the trailer system for SLICE is in the development of a safe functional connection design. The properties of the connection between the SLICE vessel and the trailer will have a pronounced influence on the dynamic response of the system as a whole. The response of the connection between the two floating vessels is identified as an area of high risk. Development of proper analytical modeling procedures capable of capturing the response of 2 floating modules with flexible connectors is identified as a preliminary measure toward risk mitigaiton. The modeling procedures can be calibrated using existing data on 2-module floating systems such as collected under the ONR Mobile Offshore Base program. Once a functional modeling procedure is established, properties of the SLICE, trailer and chosen connection can be implemented to study the system dynamics.

A survey of potential connections are discussed in this report as a starting point for connector design in a SLICE/trailer system. Proper estimation of the connectors' influence on the dynamic response will avoid risk associated in development of control systems algorithms to be used in operation of the vessels. Relative motion between the SLICE and the trailer may contribute to large connector forces at sea. This relative motion can also have a significant effect as the two modules are brought together while the connection is being made. Therefore, developing of a proper docking system is deemed to be a critical issue in the connection design

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## 6. SELECTED BIBLIOGRAPHY


Berkelder, A.G., Jongh, A.W., and Hill, N.W., (1989), "Flexible Deck Joints for Troll GBS Platform", Eighth International Conference on Offshore Mechanics and Arctic Engineering, The Hague, March 19-23.

Colliat, J.L., Boisard, P., Andersen, K., and Schroeder, K., (1995), "Caisson Foundations as Alternative Anchors for Permanent Mooring of a Process Barge Offshore Congo", 27th Annual Offshore Technology Conference, Houston TX, V2, p919-929.

Derstine, M.S., Brown, R.T., (1999), "A Compliant Connector Concept for the Mobile Offshore Base", Proceedings of the Third International Workshop on Very Large Floating Structures (VLFS '99), Vol. II, p641-650, Honolulu, Hawaii, USA.

Garrison, C.J., (1994), "Hydrodynamic Load and Motion of Pontoon Modules in Seaways for Barge Connecting Systems", Technical Memorandum TM-2024-AMP(CR), Naval Facilities Engineering Service Center, Port Hueneme, California.

Haney, J.A., (1999), "MOB Connector Development", Proceedings of the Third International Workshop on Very Large Floating Structures (VLFS '99), Vol. II, p651-659, Honolulu, Hawaii, USA.

Hatch, W.G., (1985), "Development of P-8 Pontoon-Flexor End Connector System for Navy Pontoon Causeway Equipment", Naval Civil Engineering Laboratory, Technical Note N-1727, Port Hueneme, California.

Hopkin, D., Preston, J.M., and Latchman, S., (1993), "Effectiveness of a Two-Part Tow for Decoupling Ship Motions", Defence Research Establishment Pacific Tech memo, 359-364, British Crown, Victoria, BC, Canada.

Huang, E.T., (1996), "An Open Modular Construction Method: Rigid Pontoon Connector", Proceedings of the Sixth International Offshore and Polar Engineering Conference, p553-558, Naval Facilities Engineering Center, Port Hueneme, CA.

Huang, E. T., (1995) "Conceptual Development of Open Sea Module Connection Techniques", Technical Memorandum, TM-2067-AMP, Naval Facilities Engineering Service Center, Port Hueneme, CA.

Huang, T.S., (1990), "Interaction of Ships with Berth at Floating Terminals", Technical Memorandum TM-65-90-03, Naval Civil Engineering Laboratory, Port Hueneme, California.

Mills, T.R.J., and Chen, L., (1999), "Evaluation of Nonlinear Compliant Connector for Mobile Offshore Base", 18th International Conference on Offshore Mechanics and Arctic Engineering (OMAE), St. John's, Newfoundland, Canada. OMAE99-4190. 7pp.

McAllister, K.R., (1996), "Mobile Offshore Bases – An Overview of Recent Research", Proceedings of the International Workshop on Very Large Floating Structures (VLFS '96), Hayama, Japan.

Plackett, M.J., (1993), "Design Concepts for the Ocean Barge Module Connection System", Naval Facilities Engineering Service Center, Port Hueneme, CA, Western Instrument Corporation, Ventura, California, December.

Rae, G.J.S., Smith, S.M., Anderson, D.T., and Shein, A.M., (1993), "A Fuzzy Rule Based Dockiing Procedure for Two Moving Autonomous Underwater Vehicles", Proceedings of the American Control Conference, San Francisco, California.

Riberio, E.J.B., Roveri, F.E., Mourelle, M.M., and Petrobus, S.A., (1998), "Dynamic Compression Buckling in Flexible Riser", ", $30^{th}$ Annual Offshore Technology Conference, Houston, TZ, V2, p19-27.

Riggs, H.R., Ertekin, R.C., (1993), "Approximate Methods for Dynamic Response of Multi-Module Floating Structures", Marine Structures, Elsevier Science Publishers Ltd, England.

Stokey, R., Purcell, Mi., Forrester, N., Austin, T., Goldsborough, R., Allen, B., and von Alt, C., (1997), "A Docking System for REMUS, an Autonomous Underwater Vehicle", MTS/IEEE Conference Proceedings, Halifax, Nova Scotia, p1132-1136.

Venkataraman, Vijay, (2001), "Dynamic Response of A Mobile Offshore Base Hydroelastic Test Model", University of Maine, Department of Mechanical Engineering, Masters Thesis, August.

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**14. ABSTRACT**

This report documents a review of concepts for interconnection of a trailer and the SLICE vessel. The long-term goal is to develop a safe method of attaching a trailer to the SLICE vessel for swift and effective transport of personnel and cargo. The main objective of this particular work is to present a list of viable concepts for the SLICE/trailer connection and to identify risk mitigation measures. A summary of viable concepts found from a review of the literature is presented along with a brief discussion of the dynamics of a flexibly connected 2-Module floating system. Proper quantification of the connection's influence on the dynamic response is imperative if the SLICE/trailer system operation is to be controlled effectively.

**15. SUBJECT TERMS**

SLICE/trailer; Inter-modular connectors; High speed hull forms; Connection dynamics; Modal response.

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